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RESEARCH MEMORANDUM

EFFECT OF LARGE DEFLECTIONS OF A CANARD CONTROL AND DEFLECTIONS OF A WING-TIP CONTROL ON THE STATIC-STABILITY AND INDUCED-ROLL CHARACTERISTICS OF A CRUCIFORM CANARD MISSILE AT A MACH NUMBER OF 2.01

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EFFECT OF LARGE DEFLECTIONS OF A CANARD CONTROL AND DEFLECTIONS OF A WING-TIP CONTROL ON THE STATIC-STABILITY AND INDUCED-ROLL CHARACTERISTICS OF A CRUCIFORM CANARD MISSILE AT A MACH NUMBER OF 2.01

By M. Leroy Spearman

SUMMARY

An investigation has been conducted in the Langley 4- by 4-foot supersonic pressure tunnel at a Mach number of 2.01 to determine the static stability and control characteristics of a canard-type missile configuration with large deflections of the canard controls and with deflection of wing-tip controls. The missile had cruciform wings and canard surfaces of delta plan form with 70° swept leading edges and had a body finess ratio of 15.7.

The results of the investigation indicated that with a 30° deflection of the canard control a maximum trim normal-force coefficient of 0.4 and a maximum trim angle of attack of 12° might be obtained for the optimum center-of-gravity location. The same values of normal force and angle of attack might be obtained with considerably less chord force by simultaneously deflecting the canard control 12° and the wing-tip control -20°. Deflecting the ailerons on the vertical wings resulted in greater rolling moments, higher adverse yawing moments, and slightly higher chord force than did deflections of the aileron on the horizontal wing. Deflections of the vertical canard through an angle-of-attack range resulted in large variations of induced roll, directional control, and lateral force above an angle of attack of 10° that might lead to complicated flight control problems.

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INTRODUCTION

In connection with the development of missile configurations with canard controls, an investigation has been conducted in the Langley 4- by 4-foot supersonic pressure tunnel to determine the longitudinal and lateral aerodynamic characteristics of a series of such configurations. The models had cruciform wings and canard controls of delta plan form with 70° swept leading edges and were equipped with all-movable canard surfaces for both pitch and yaw control and movable wing-tip ailerons for roll control.

The results of an investigation of the effects of body length on the longitudinal stability and control characteristics of these missiles at a Mach number of 2.01 are presented in reference 1. The aerodynamic characteristics of the canard surfaces in the presence of one of the bodies at a Mach number of 1.61 are presented in reference 2.

This paper presents the results of an investigation made at a Mach number of 2.01 to determine the effects of large deflections of the canard control and deflections of the wing-tip controls on the stability and control characteristics of a missile having a body fineness ratio of 15.7.

COEFFICIENTS AND SYMBOLS

The results of the tests are presented as standard NACA coefficients of forces and moments. The data are referred to the body-axis system (fig. 1) with the reference moment center located at -19.5 percent of the wing mean aerodynamic chord (6.25 body diameters forward of the base of the body).

The coefficients and symbols are defined as follows:

C_N	normal-force coefficient (N/qS)
C_C	chord-force coefficient (C/qS)
C_m	pitching-moment coefficient $(M'/qS\bar{c})$
C_n	yawing-moment coefficient $(N'/qS\bar{c})$
C_Y	lateral-force coefficient (Y/qS)

C_l	rolling-moment coefficient (L/qSb)
N	normal force
C	chord force
M'	pitching moment
N'	yawing moment
Y	lateral force
L	rolling moment
q	free-stream dynamic pressure
S	total wing area (two panels) resulting from extending the wing leading edge and trailing edge to the body center line
$\bar{c}$	wing mean aerodynamic chord
b	wing span
M	Mach number
x	distance along body axis
α	angle of attack, deg
ϕ	roll angle, deg
δ	control deflection, deg

Subscripts:

V	vertical canard
H	horizontal canard
a_s	symmetrical deflection of wing-tip ailerons
a_d	differential deflection of wing-tip ailerons
t	trim

MODEL AND APPARATUS

Details of the model are shown in figure 2 and the geometric characteristics of the model are presented in table I. The body of the model had a fineness ratio of 15.7 and was composed of a parabolic nose followed by a frustum of a cone which was faired into a cylinder. Coordinates for the body are given in table II. The canard surfaces and the wing had delta plan forms with 70° swept leading edges and hexagonal sections. Tip ailerons of triangular plan form were provided on one pair of wings only. The horizontal canard was motor driven and deflections up to 12° could be set remotely. Deflections of the vertical canard and of the ailerons were made manually.

Force and moment measurements were made through the use of a six-component internal strain-gage balance. The model was mounted in the tunnel on a remotely controllable rotary-type sting. For the present investigation, roll angles of only 0° and 90° were used. The sting angle range was from 0° to about 27°.

TESTS AND CORRECTIONS

Test Conditions

The conditions for the tests were:

Mach number	2.01
Reynolds number, based on wing M.A.C.	3.47×10^6
Stagnation pressure, atm	1.0
Stagnation temperature, °F	110

The stagnation dew point was maintained sufficiently low (-25° F or less) so that no condensation effects were encountered in the test section.

Corrections and Accuracy

The angle of attack was corrected for the deflection of the balance and sting under load. The Mach number variation in the test section was approximately ±0.01 and the flow-angle variation in the vertical and horizontal planes did not exceed about ±0.1°. No corrections were applied to the data to account for these flow variations. The base pressure was measured and the chord force was adjusted to a base pressure equal to the free-stream static pressure.

The estimated errors in the individual measured quantities are as follows:

C_N	± 0.004
C_C	± 0.002
C_m	± 0.0004
C_n	± 0.0005
C_Y	± 0.001
C_l	± 0.0004
α, deg	± 0.1
φ, deg	± 0.1
δ, deg	± 0.1

RESULTS AND DISCUSSION

Longitudinal Stability and Control

Effect of large deflections of canard controls.- The results presented in figure 3 were obtained at a roll angle ϕ of 90° (corresponding to the sideslip plane) with the vertical canards deflected as the controlling surface. The pitching-moment and normal-force coefficients shown were obtained from the yawing-moment and lateral-force measurements. The variations of C_N, C_C, and C_m with α for control deflections up to 30° (fig. 3) indicates little change in total lift due to deflection but large increases in C_C with deflection. The pitching effectiveness decreases considerably with increasing angle of attack and deflection until at $\alpha \approx 20^{\circ}$, the 30° deflected control was no more effective than the 20° deflected control. The variations of $C_{m(\alpha = 0)}$, α_t, and C_{N_t} with control deflection are fairly linear (fig. 4). For a control deflection of 30° the maximum trim angle of attack is 6.6° and the maximum trim C_N is 0.23. These results are for a center-of-gravity location (moment reference point) at -19.5 percent of the wing mean aerodynamic chord. Because of the linearity of the pitching-moment curves it might be expected that the center of gravity could be shifted rearward so that the static margin may be reduced and the controllability increased. The results presented in figure 5 indicate that the center-of-gravity location could be shifted to at least -4.5 percent of the mean aerodynamic chord without the occurrence of second trim points for any control deflection and the resulting trim angle of attack then is about 12° with a corresponding trim C_N of about 0.4. The feasibility of such a shift in the center-of-gravity location for a specific missile would, of course, depend upon the weight distribution of the missile. Hence, from a practical

standpoint, it may not be possible to obtain a center-of-gravity location as far aft as -4.5 percent of the wing mean aerodynamic chord.

Effect of symmetrical deflections of the wing-tip control.- At a roll angle of 0° (corresponding to the angle-of-attack plane), the wing-tip controls that would ordinarily be used for roll control were deflected symmetrically as pitch controls. For a deflection of -20° the resulting trim angle of attack is about 3.3° (fig. 6), which is equivalent to that produced by a canard deflection of about 9°. (See fig. 4.) A horizontal-canard deflection of 12° (shown on fig. 6) produced a trim angle of about 4.5° and, when deflected simultaneously with a tip-control deflection of -20°, the trim angle of attack is about 6.9°. This angle is about the same as that produced with $\delta_V = 30°$ at 90° roll (fig. 4). It is probable that the center-of-gravity location could be shifted for the results shown in figure 6 by the same amount as that shown in figure 5 (from $0.195\bar{c}$ to $-0.045\bar{c}$), so that trim angles of about 12° might be expected from the combined deflections of $\delta_H = 12°$ and $\delta_{a_s} = -20°$. For those cases where the tip controls are deflected symmetrically, the variation of pitching effectiveness with α is essentially linear.

An advantage to be gained from the use of tip controls for longitudinal trim results from the fact that lower chord forces at high angles of attack may be obtained in this manner (fig. 6). The chord force resulting from deflection of the canard surfaces tends to increase with α, since the angle of attack of the canard continues to increase with α. For the tip ailerons located aft of the center of gravity, however, the chord force due to deflection decreases with α, since the angle of attack of the ailerons decreases initially as α is increased. For $\delta_{a_s} = -20°$ the chord force due to deflection decreases with α until at $\alpha = 20°$ the chord force is about equal to that for the model with undeflected controls.

In comparison to the results obtained for large deflections of the canard (fig. 3), it appears that smaller deflections of the canard in conjunction with wing-tip controls might produce the same trim angles of attack with considerably less chord force.

Lateral Control

Effect of differential deflections of the wing-tip control.- The effectiveness of the wing-tip aileron was investigated at $\phi = 0°$ (ailerons in horizontal plane) and at $\phi = 90°$ (aileron in vertical plane) (fig. 7). The ailerons deflected on the vertical wing resulted in greater rolling moments, higher adverse yawing moments, and a slightly higher chord force than did the aileron on the horizontal wing. The rolling moment produced by aileron deflection at $\varphi = 0°$ is in

reasonably good agreement with that predicted by the method of reference 3. The larger rolling moment produced at $\varphi = 90^{\circ}$ probably results from an increase in the lift effectiveness of the control on the lower wing panel as the angle of attack is increased, similar to that shown in reference 2 for a pitch control as the angle of sideslip is increased.

Effect of Angle of Attack on the Stability Characteristics with the Vertical Canard Deflected

Induced roll.- A rolling moment is induced on the wings of a canard-type missile at an angle of attack when the forward control surface is deflected to produce a change in the angle of sideslip. This type of induced roll is shown for a similar configuration in reference 4 and the characteristic result is that shown in figure 8. The initial negative rolling moment probably results primarily from the vorticity of the lower vertical canard panel acting on both the vertical and horizontal wings. The change toward positive roll occurs as the field of vorticity from the lower canard passes around the body and influences a positive roll from the vertical wings. At values of α above 20°, the induced roll for each control deflection is about the same and reduces toward zero roll as an indication that the wings are progressively moving out of the field of vorticity from the canard surfaces.

Directional control.- The directional control effectiveness, is essentially linear up to $\alpha \approx 10^{\circ}$ but then becomes quite dependent upon the angle of attack with large changes in effectiveness indicated in the α range from 10° to 26° (fig. 8). Similar trends would occur in the variation of pitching effectiveness with sideslip for the pitch control. This variation may be associated with the geometric plan form of the wing in such a manner that a greater portion of the wing area is affected as the field of vorticity from the vertical canards moves upward. As a result, the increased lateral force at the wing would tend to reduce the moment produced by the canards. Such a variation would complicate the missile control problem, inasmuch as the amount of control deflection required for a given manuever or the moment produced by a given control deflection would be different depending upon the attitude of the missile.

Lateral force.- The flight behavior of the missile might be further complicated by the effect of δ_V on the variation of C_Y with α (fig. 8). Large changes in the variation of C_Y with δ_V occur up to $\alpha = 18^{\circ}$, after which this effect decreases rapidly up to $\alpha = 26^{\circ}$. This variation may result partly from the previously discussed induced lateral force on the vertical wing from the lower vertical canard field

of vorticity and partly from the increased loading on the lower vertical canard itself as the angle of attack is increased. In addition, the field of vorticity from the canards may affect the characteristics of the body itself. A similar variation in the normal-force derivatives with sideslip might be expected to occur and as a consequence a change in sideslip required for a lateral maneuver might also result in a large change in normal acceleration.

CONCLUSIONS

The results of tests made at a Mach number of 2.01 to determine the effects of large deflections of a canard control and deflections of a wing-tip control on the static-stability and induced-roll characteristics of a cruciform canard-type missile indicated the following conclusions:

1. Fairly linear variations of pitching-moment coefficient, trim normal-force coefficient, and trim angle of attack with canard deflection might be obtained with a maximum trim normal-force coefficient of 0.4 and a maximum trim angle of attack of 12° being possible with a canard deflection of 30° for the optimum center-of-gravity location.

2. A -20° deflection of the wing-tip controls in conjunction with a 12° canard deflection produced about the same maximum trim normal-force coefficient and trim angle of attack as did 30° of canard deflection alone but with considerably less chord force.

3. Deflected ailerons on the vertical wing resulted in greater rolling moments, higher adverse yawing moments, and a slightly higher chord force than did the aileron on the horizontal wing.

4. Deflections of the vertical canard through the angle of attack range resulted in large variations of induced roll, directional control, and lateral force, particularly at an angle of attack above about 10°. Similar variations would be expected in the pitching moment and normal force for a deflected horizontal canard operating through a sideslip-angle range. Such variations might lead to complicated flight control problems for the type of missile considered.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., October 16, 1953.

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1. Spearman, M. Leroy: Aerodynamic Characteristics in Pitch for a Series of Canard-Type Cruciform-Wing Missiles at a Mach Number of 2.01. NACA RM L53I14, 1953.

2. Spearman, M. Leroy: Component Tests to Determine the Aerodynamic Characteristics of an All-Movable 70° Delta Canard-Type Control in the Presence of a Body at a Mach Number of 1.6. NACA RM L53I03, 1953.

3. Kainer, Julian H., and King, Mary Dowd: The Theoretical Characteristics of Triangular-Tip Control Surfaces at Supersonic Speeds. Mach Lines Behind Trailing-Edges. NACA TN 2715, 1952.

4. Chubb, Robert S.: Experimental Investigation of the Stability, Control, and Induced Rolling Moments of a Canard Missile Airframe at a Mach Number of 1.7. NACA RM A52G29, 1952.

TABLE I.- GEOMETRIC CHARACTERISTICS OF MODEL

Wings:	
Span, in.	11.853
Chord at body center line, in.	17.069
Chord at body intersection, in.	13.407
Chord at aileron break line, in.	4.606
Area (leading and trailing edges of one pair of panels extended to body center line), sq in.	104.8
Area (exposed), sq in.	64.16
Aspect ratio	1.404
Sweep angle of leading edge, deg	70
Thickness ratio at body center line	0.0147
Thickness ratio at aileron break line	0.0543
Leading edge angle normal to leading edge, deg	15.6
Mean aerodynamic chord, in. (referenced to total area of one pair of panels)	11.48
Aileron:	
Area, sq in.	3.201
Mean aerodynamic chord	3.071
Thickness ratio at break line	0.039
Canard surfaces:	
Area (exposed), sq in.	6.406
Aspect ratio	1.73
Sweep angle of leading edge, deg	70
Mean aerodynamic chord, in.	2.576
Thickness, percent chord	4.1
Body:	
Maximum diameter, in.	2.666
Base area, sq in.	5.583
Length, in.	42.0
Fineness ratio	15.7

TABLE II.- BODY COORDINATES

Body station, in.	Radius, in.
0	0
.297	.076
.627	.156
.956	.233
1.285	.307
1.615	.378
1.945	.445
2.275	.509
2.605	.573
2.936	.627
3.267	.682
2.598	.732
3.929	.780
4.260	.824
4.592	.865
4.923	.903
5.255	.940
5.587	.968
5.920	.996
6.252	1.020
6.583	1.042
11.542	1.333
42.000	1.333

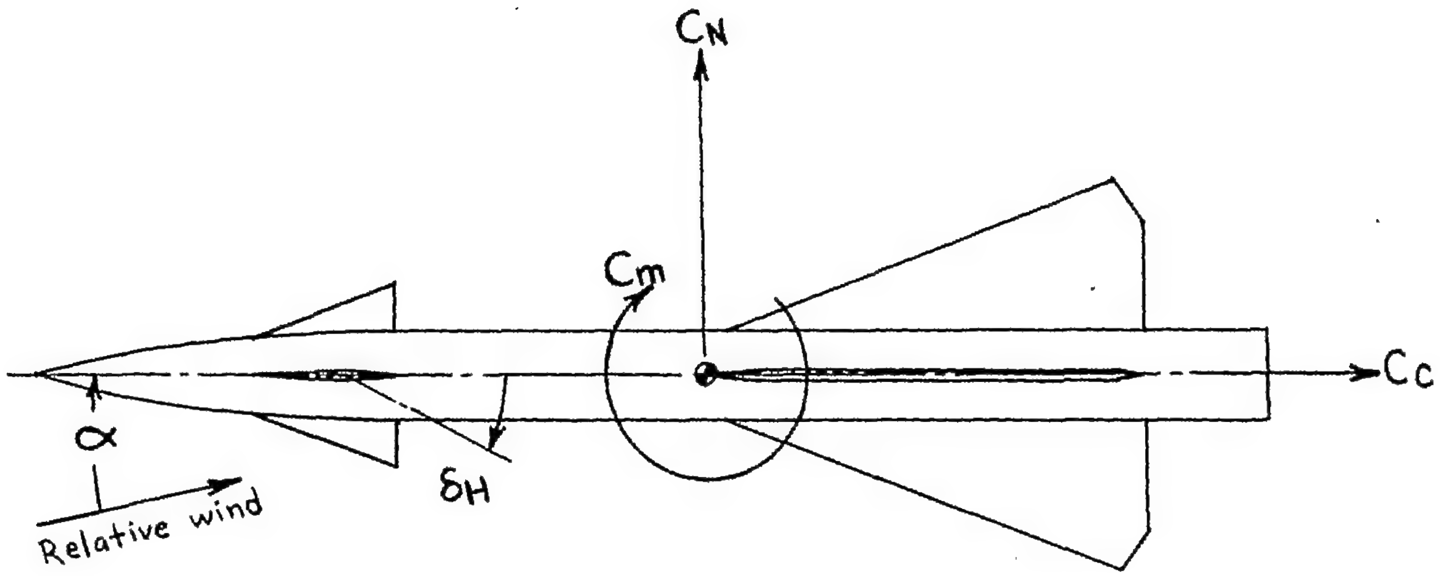
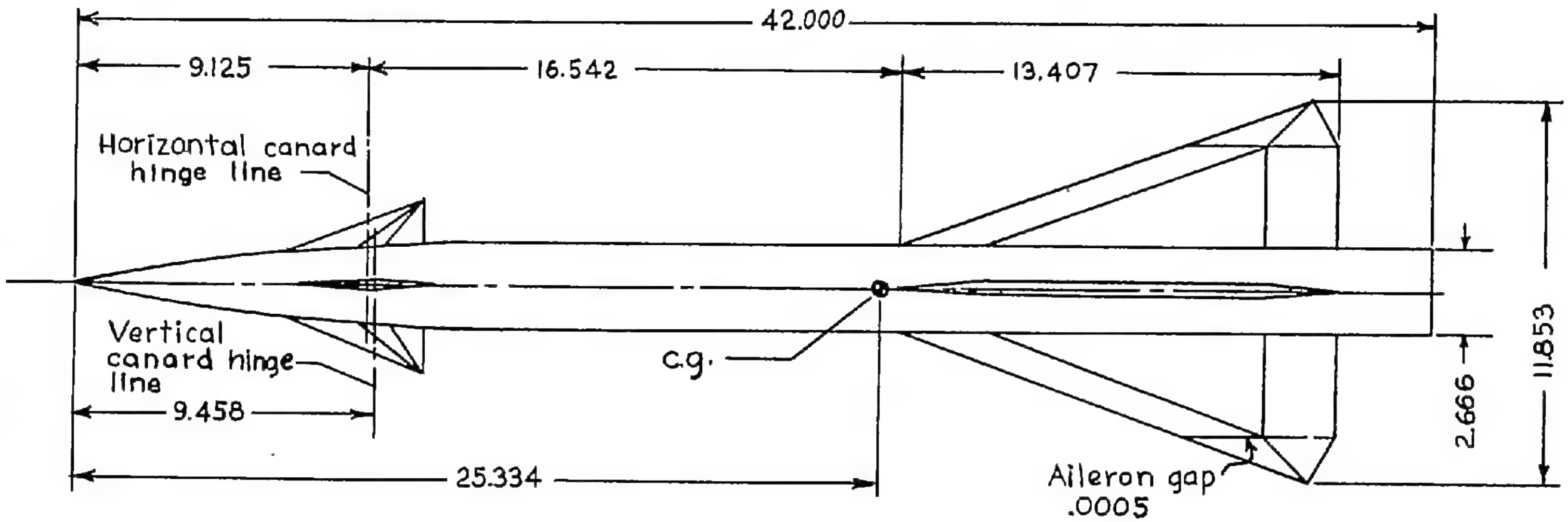
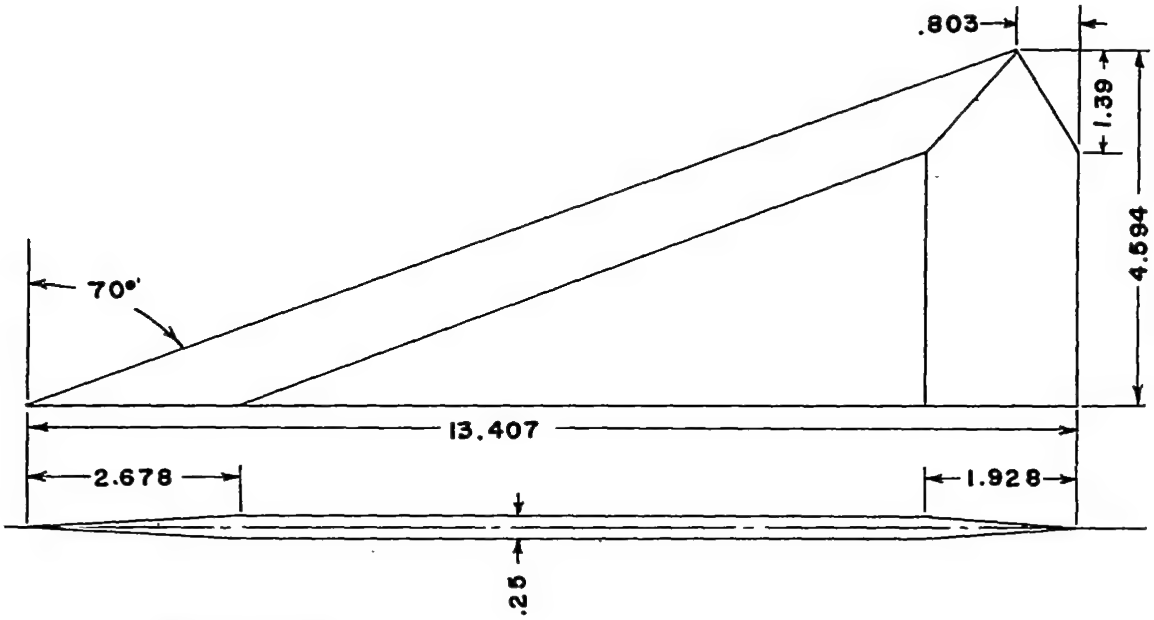


Figure 1.- System of body axes. Arrows indicate positive values and directions.

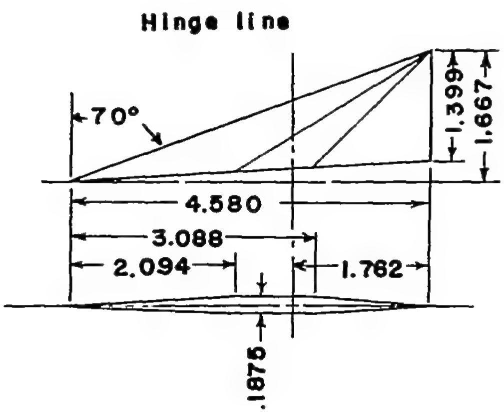


(a) Complete model.

Figure 2.- Details of model. (All dimensions in inches.)



Wing panel



Canard control panel

(b) Details of wing and canard control.

Figure 2.- Concluded.

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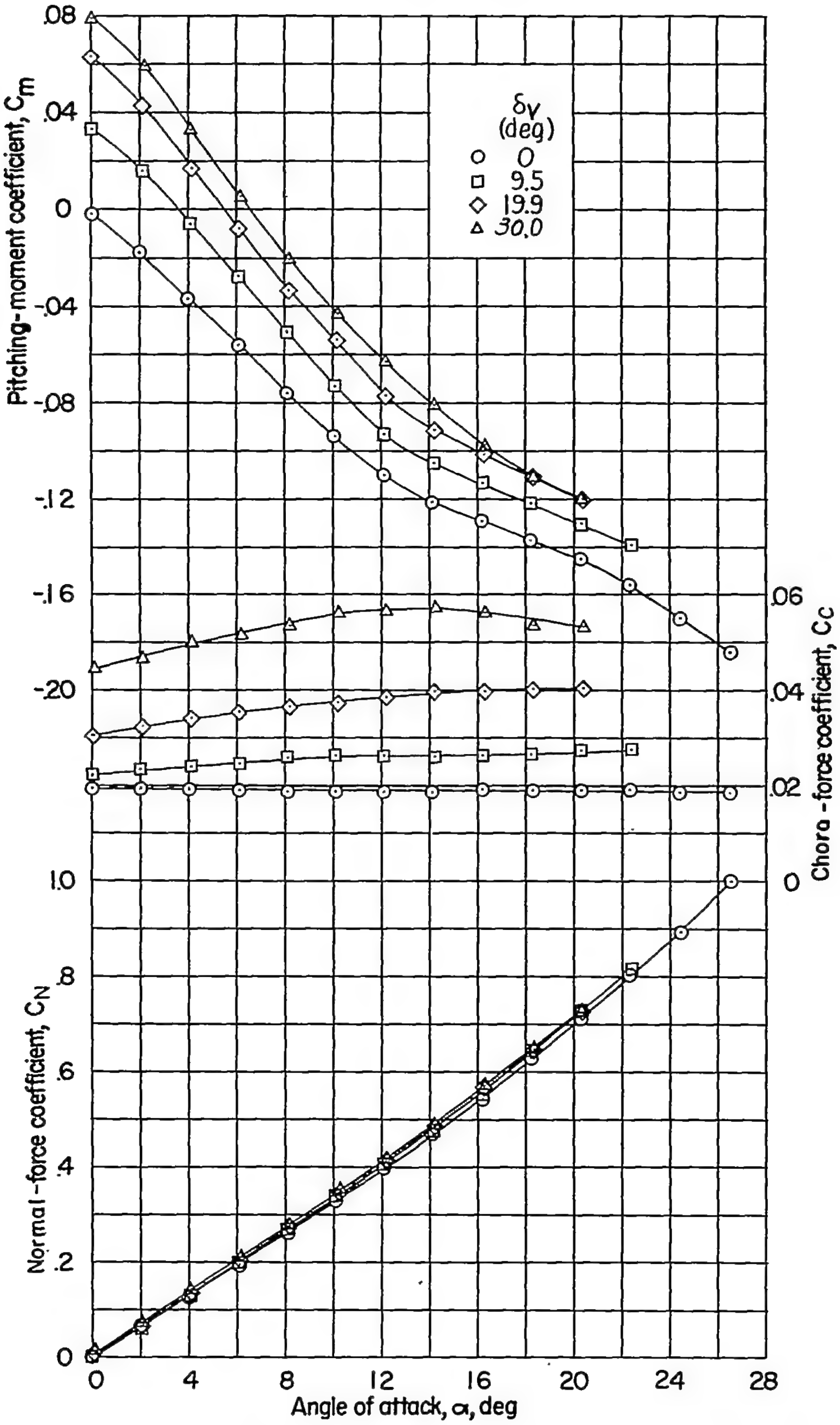

Figure 3.- Effect of canard deflection on aerodynamic characteristics in pitch. $M = 2.01$; $\phi = 90^{\circ}$.

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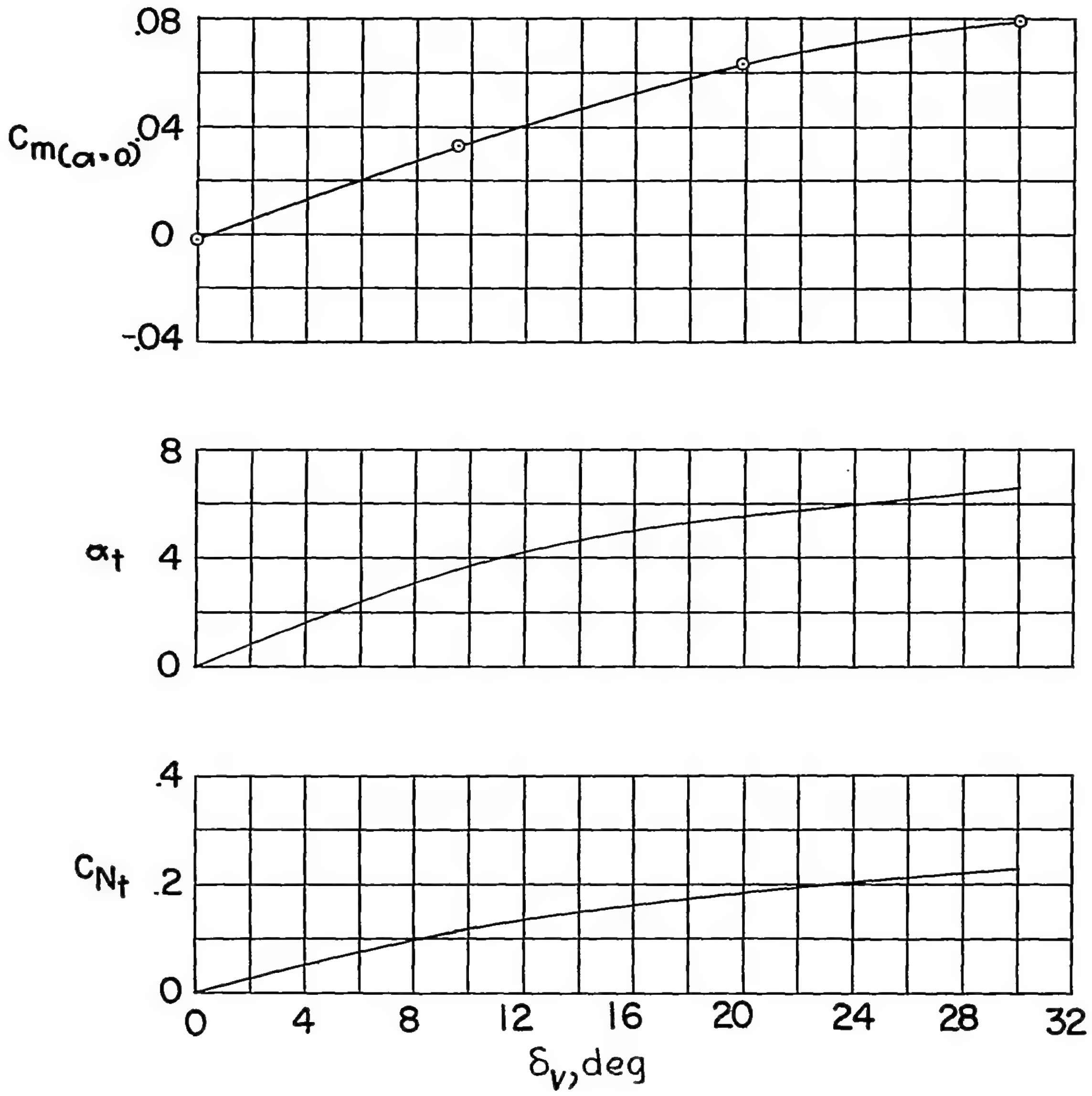

Figure 4.- Canard-control effectiveness. M = 2.01; $\phi = 90^{\circ}$.

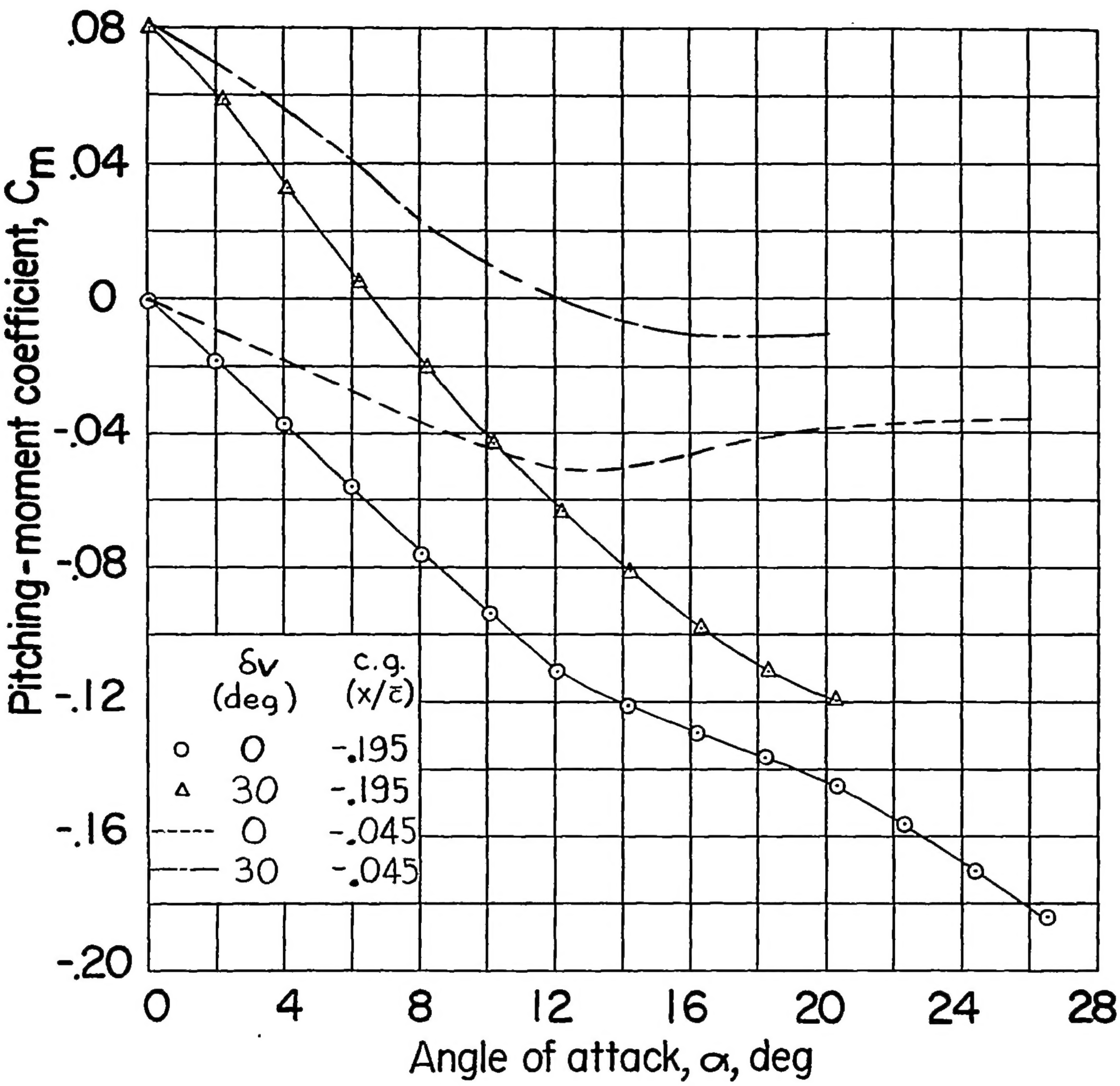

Figure 5.- Effect of center-of-gravity location on longitudinal trim characteristics. M = 2.01; $\phi = 90^{\circ}$.

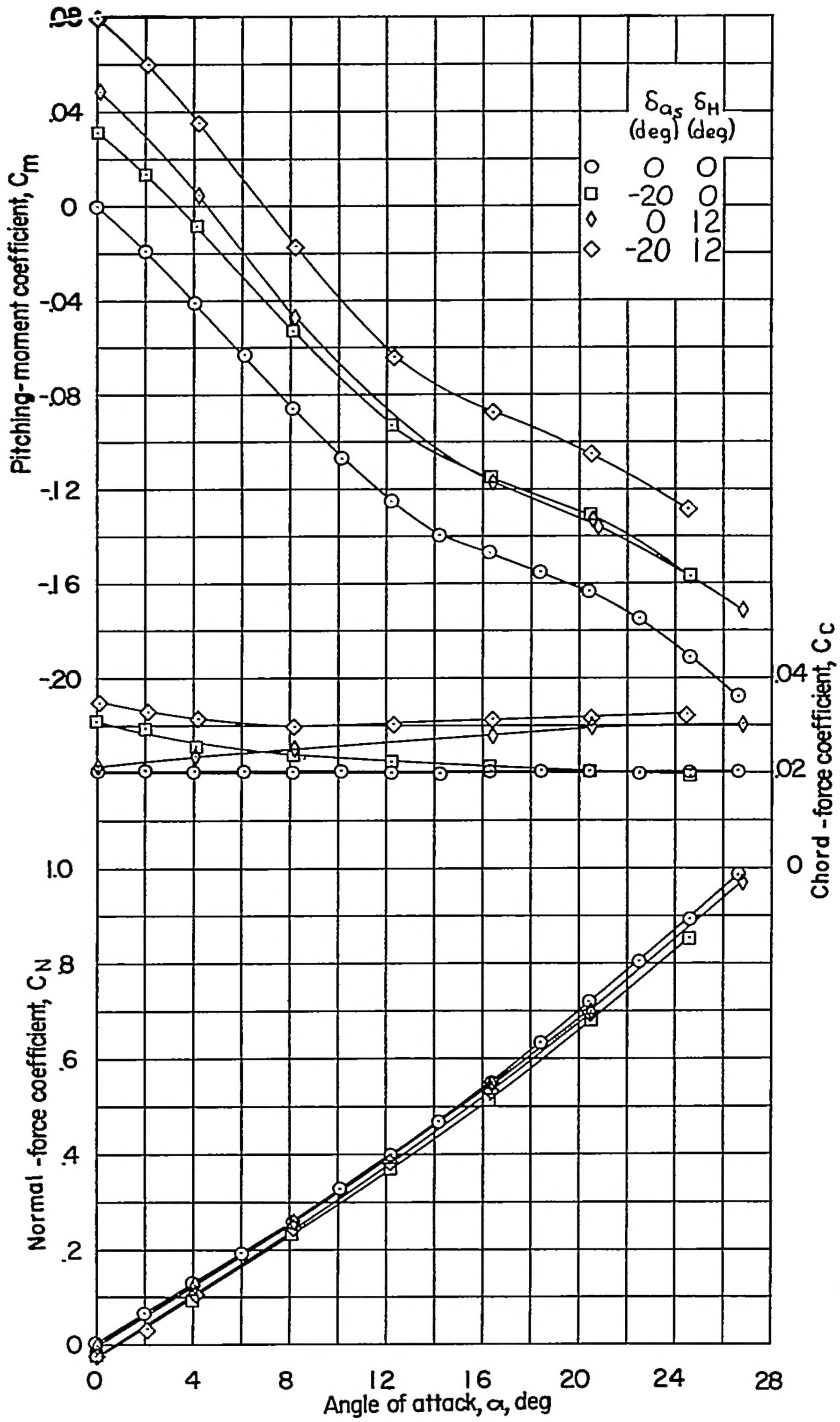

Figure 6.- Effect of wing-tip-control deflection on aerodynamic characteristics in pitch. M = 2.01; $\phi = 0^{\circ}$.

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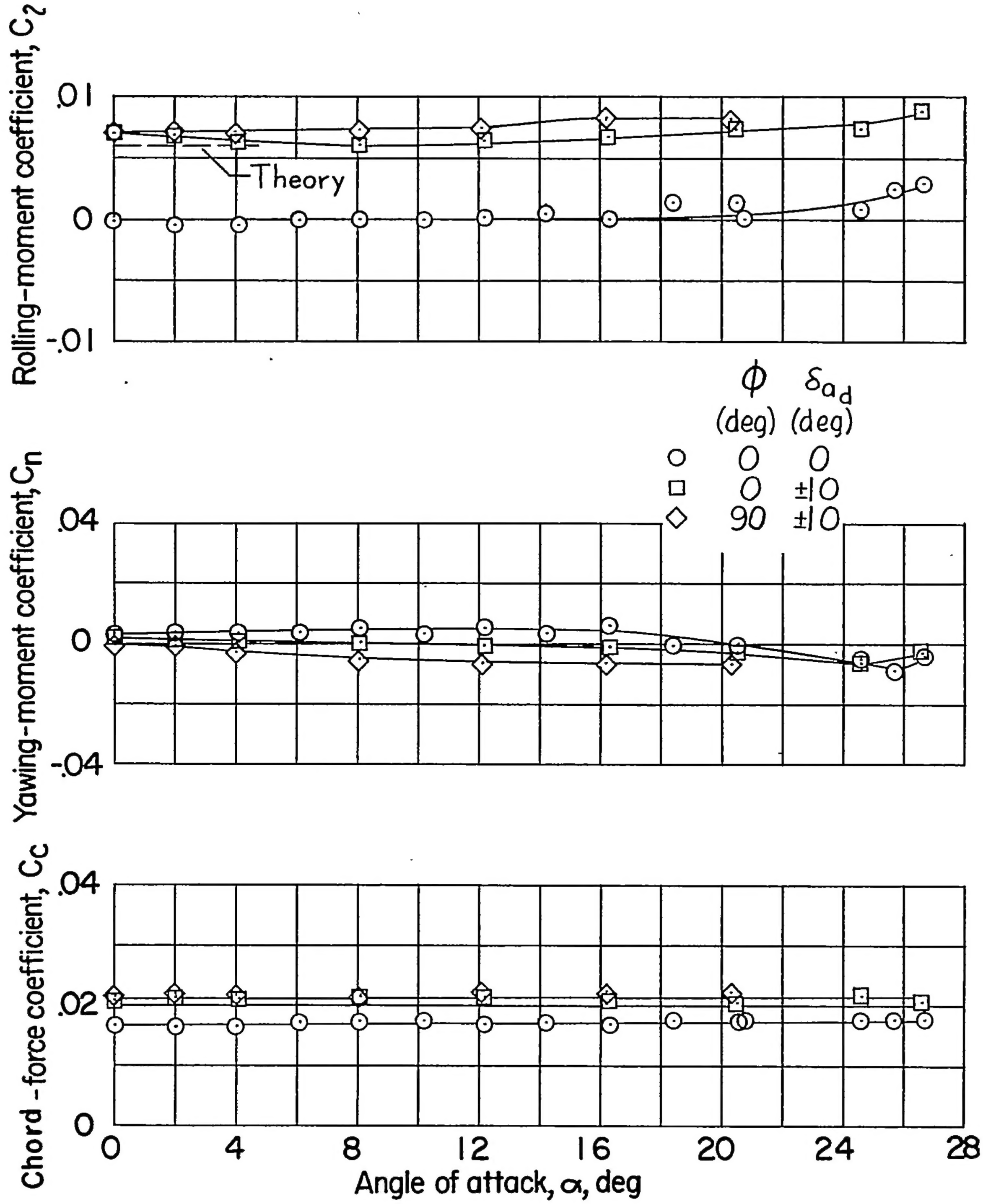

Figure 7.- Control characteristics of wing-tip ailerons. M = 2.01.

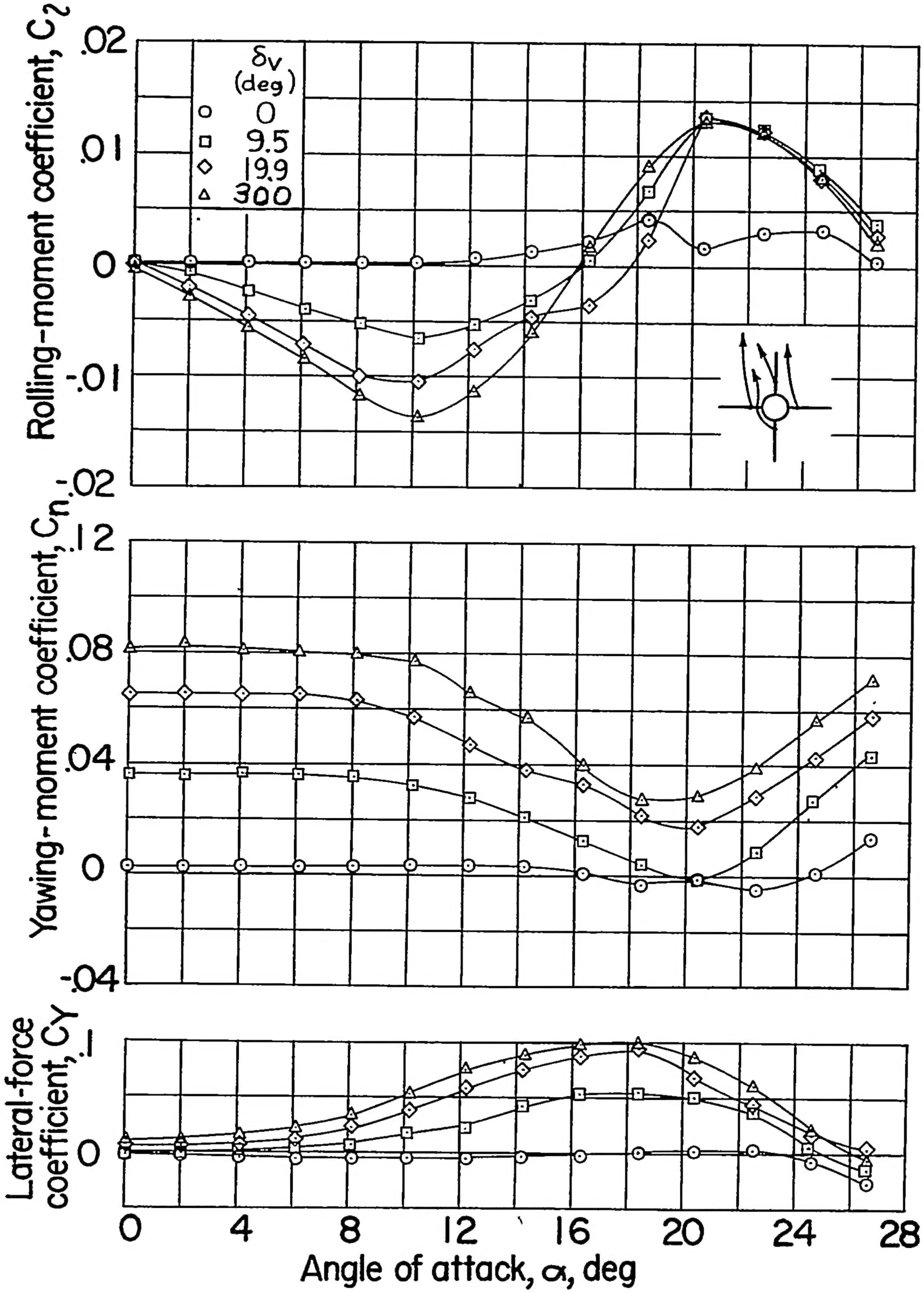

Figure 8.- Effect of angle of attack on the vertical-canard-control characteristics. M = 2.01; $\phi = 0^\circ$.